Semi-Empirical Modeling of White-Layer Formation

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Sangil Han

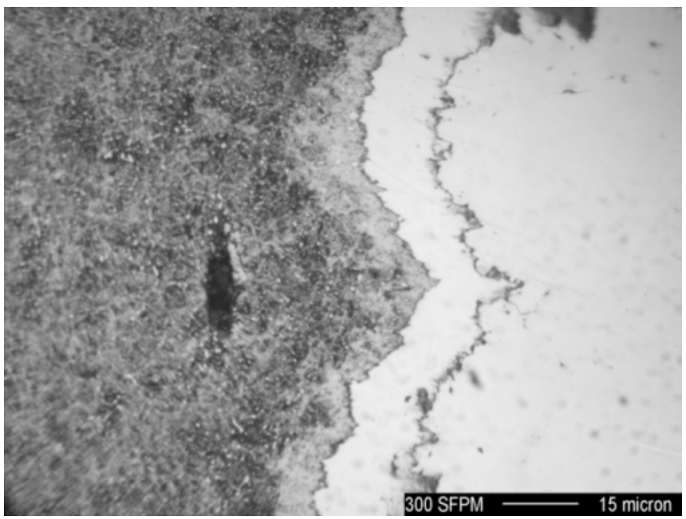
(Advisor : Dr. Shreyes N. Melkote)

Objectives

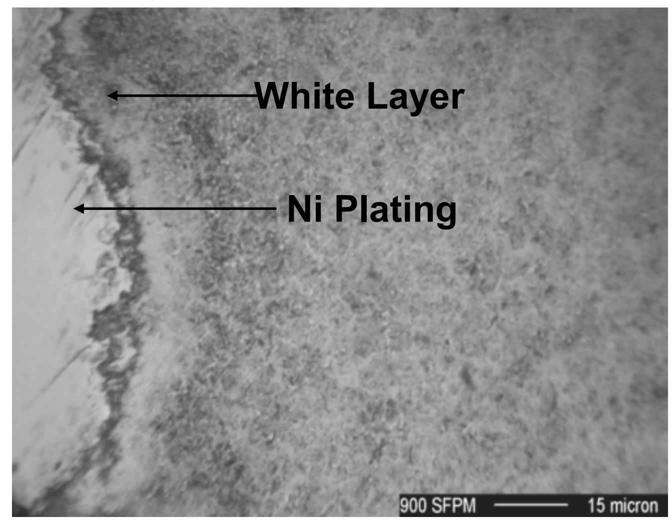
- Determination of the presence/absence of white layer
- Prediction of its depth as a function of the plastic strain and temperature produced in machining

Background

- White Layer formation mechanisms in metal cutting:
  - Severe plastic deformation that causes grain refinement
  - Phase transformation as a result of rapid heating and quenching



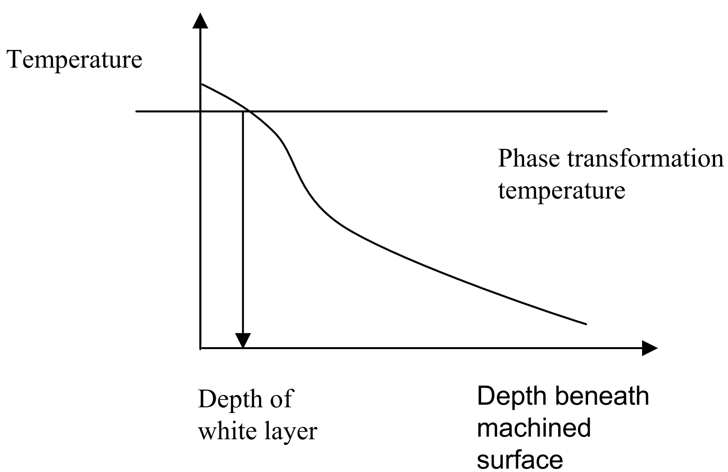
300 sfpm

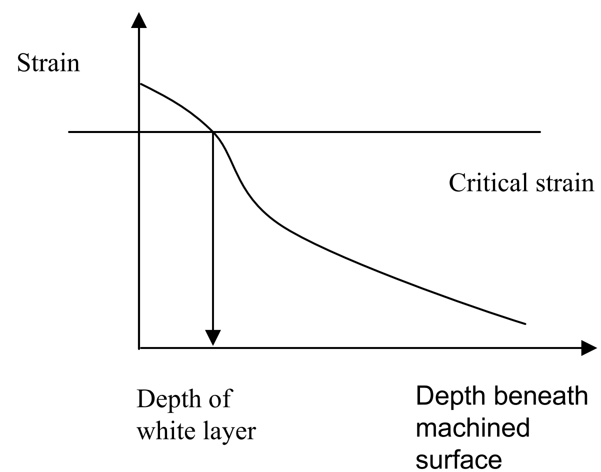


900 sfpm

Approach

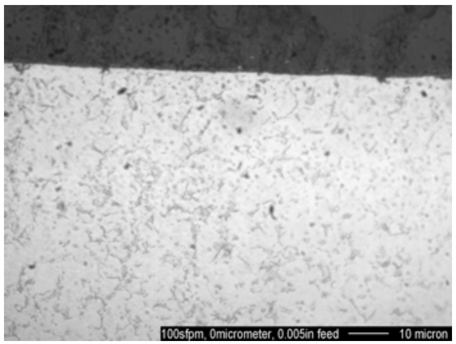
- Calculate temperature and strain distributions in workpiece from model(s).
- Use measured white layer depth and model predicted temperature and strain distributions to establish critical plastic strain and phase transformation temperature.
- Predict depth of white layer in other cutting condition with above information.



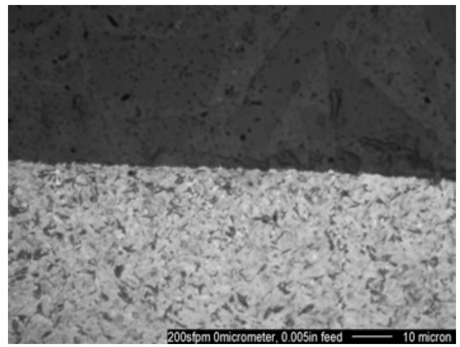


“Fresh” Tool Tests

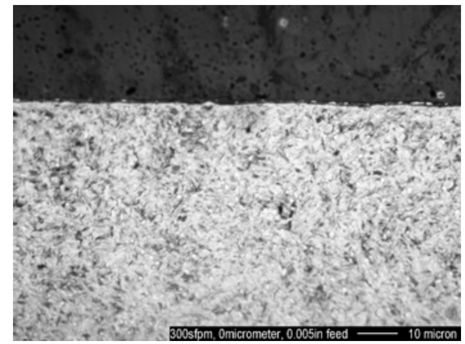
- Experiment with fresh tool (< 20μm VB) to identify critical plastic strain.



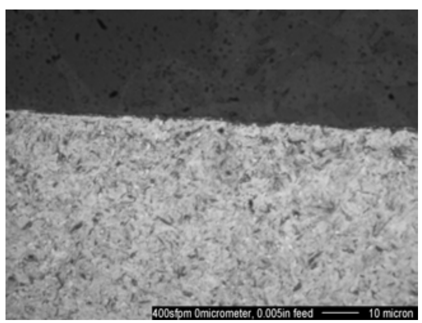
100sfpm



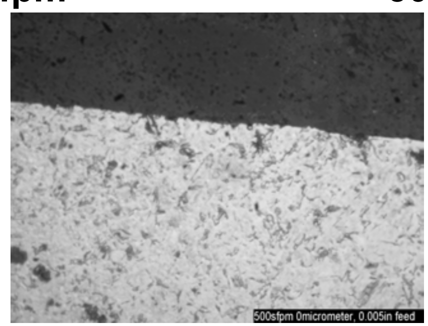
200sfpm



300sfpm



400sfpm



500sfpm

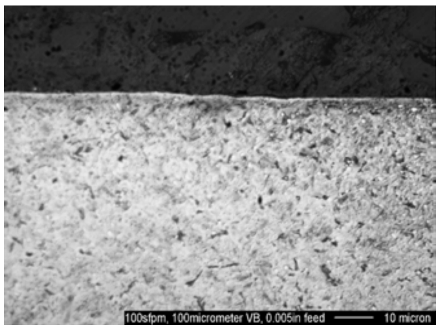
Microstructures at different cutting speeds with “unworn” tool.

“Fresh” Tool Tests

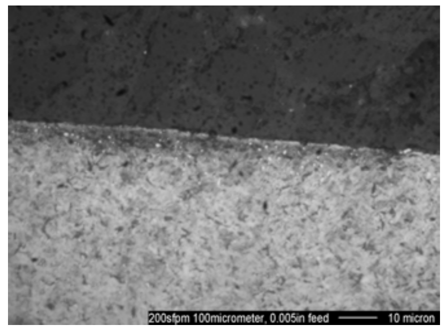
- No white layer was observed with unworn tool → Temperature and strain in the workpiece are below the critical strain and phase transformation temperature.
- Experiments with worn tool should be conducted to obtain higher temperatures and strains in the workpiece.

Worn Tool Tests

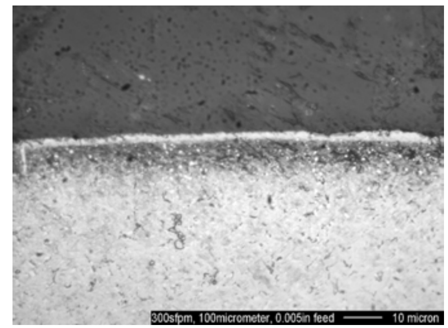
- Experiments with worn tool (100μm VB) to identify phase transformation temperature and/or critical strain.



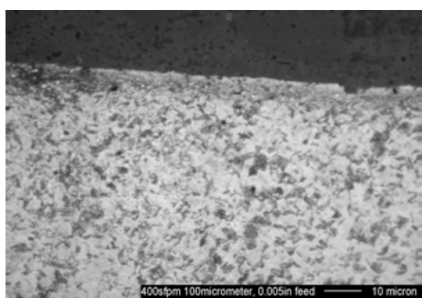
100sfpm



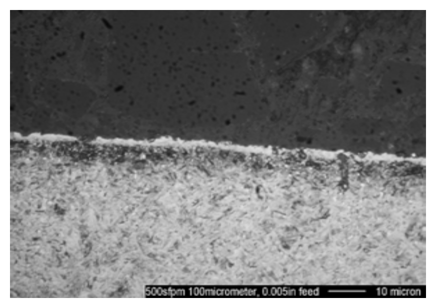
200sfpm



300sfpm



400sfpm



500sfpm

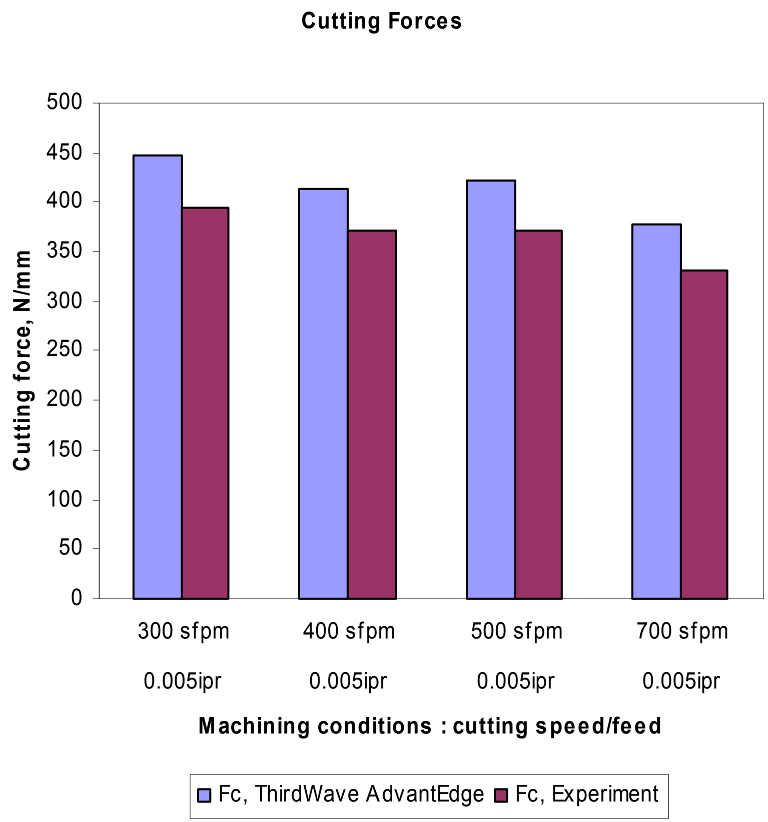
Microstructures at different cutting speeds with "worn" tool.

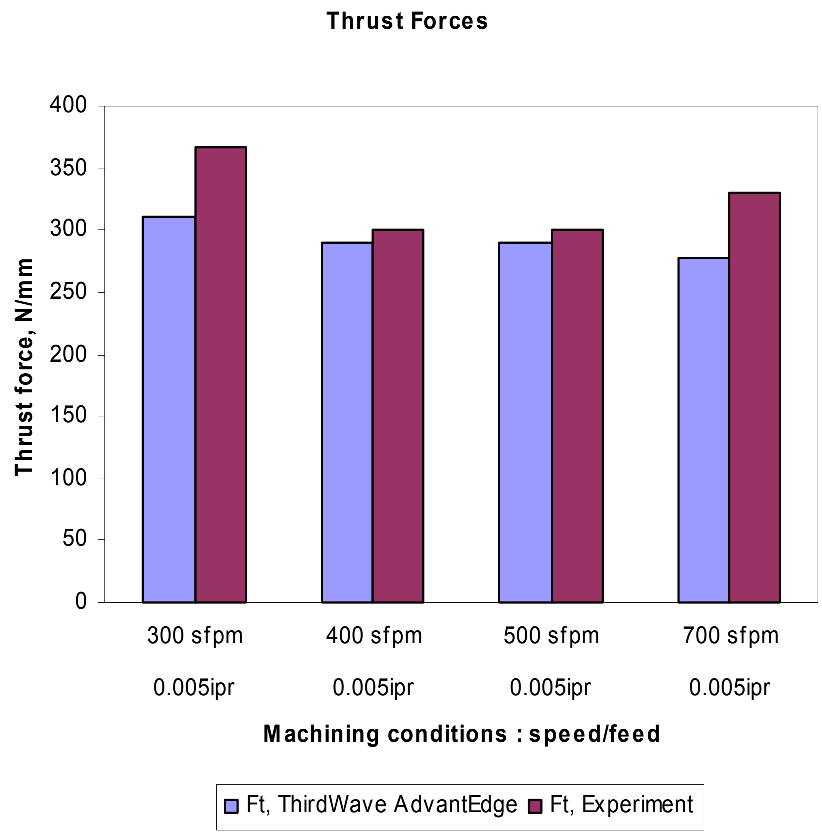
Worn Tool Tests

- White layer observed in all worn tool test cases.
- Additional heat and strain are added into the workpiece due to rubbing between flank and workpiece.
- Different depths of white layer observed with worn tool.
- Model predictions of temperature and plastic strain distribution in workpiece needed to identify critical strain and phase transformation temperature.

ThirdWave AdvantEdge® Simulation

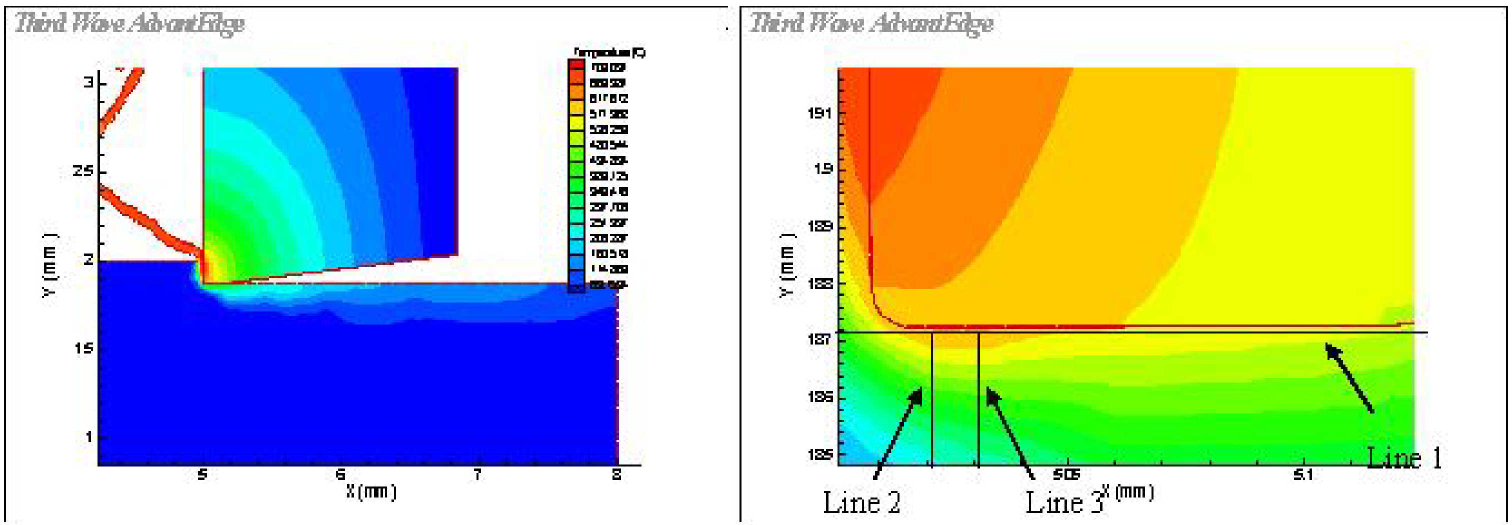
- Comparison of cutting forces





ThirdWave AdvantEdge® Simulation

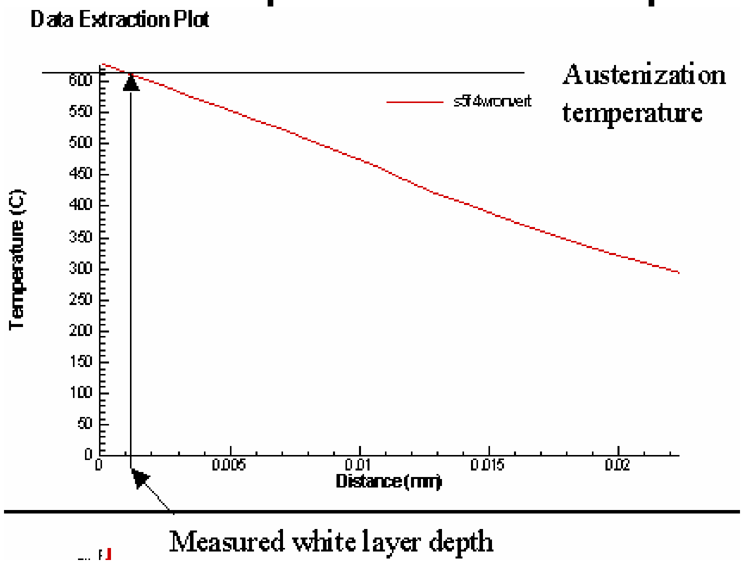
- Temperature distribution

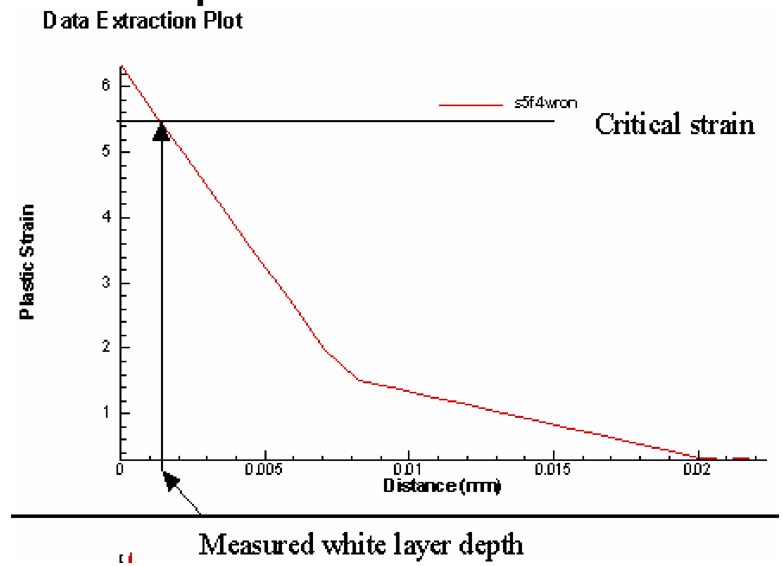


(a). Temperature distribution for 400sfpm, 0.005 in (0.127mm) feed with worn tool (100 μm flank wear). (b). Zoomed figure of temperature distribution of the interface between tool flank and workpiece.

Correlation with Experiments

- Temperature and plastic strain profile

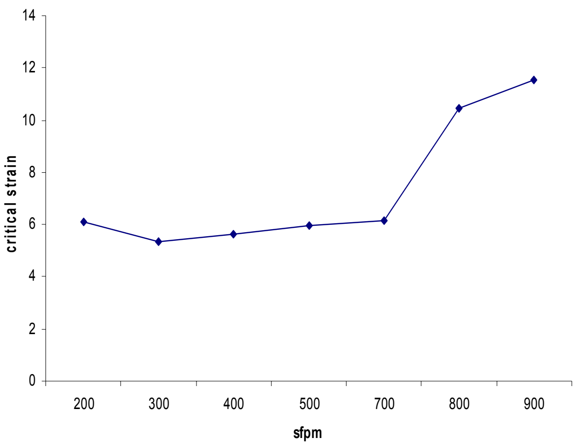


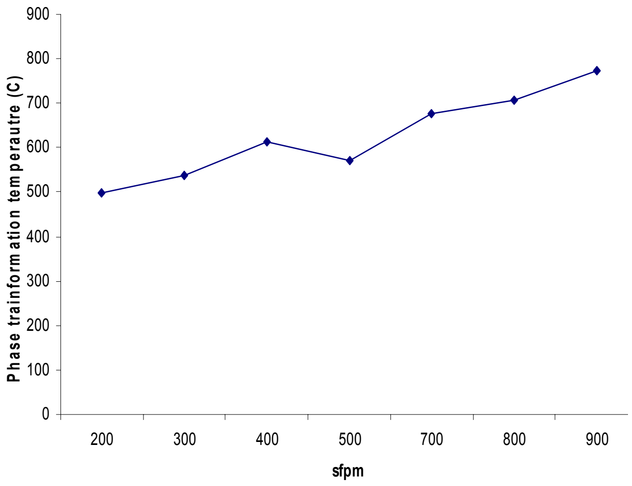


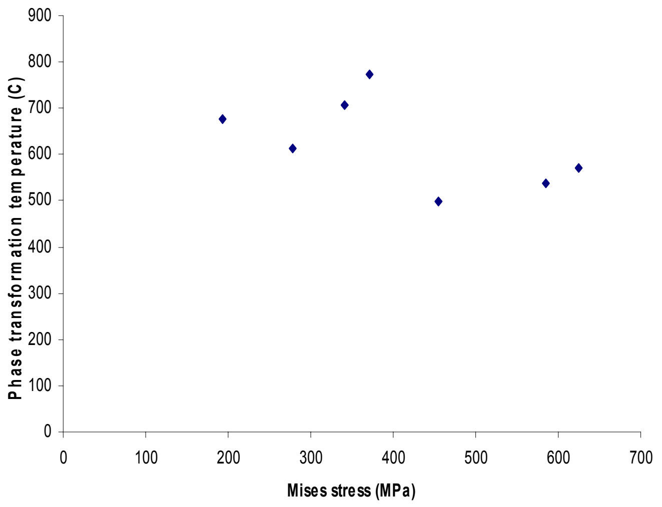
- White layer is measured to be 1.18 µm.
- Phase transformation temperature and critical strain are predicted to be 611.37ºC and 5.61, respectively.

A_s Temperature and Critical Strain

- Same criteria are applied to other cutting conditions.







- Critical strain increases as cutting speed increases.
- Phase transformation temperature is affected by stress field.

Ongoing / Future Work

- Develop comprehensive constitutive model including strain rate and stress to establish critical phase transformation temp. and critical transformation strain.
- Use critical values of temperature and strain to predict white layer depths at different conditions.